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# CONTROL OF ZEBRA MUSSELS BY ELECTROSHOCKING

Report No 91-171-K

S. McKay
Engineer
Utilization Section
Electrical Research Department

## ABSTRACT

The water intake systems of power plants are threatened with blockage by zebra mussels which were recently introduced into the Great Lakes system. The use of electricity has been proposed as a means to control mussel attachment and growth in power plants. A literature search was conducted to determine the feasibility of this proposal. Applying electric fields and electrifying metallic surfaces were found to be effective in mussel control under certain conditions. Electric field applications have been used predominantly as an antifoulant to kill post-veliger and juvenile mussels as they pass though a section of water intake pipe. Electrifying conductive surfaces was identified as an effective defoulant for adult mussels. A testing program was developed to investigate the use of electric fields on zebra mussels. A test cell was constructed and experiments were performed where mussels were exposed to electric fields ranging from 350 to 500 V/cm for durations of 0.1 to 90 s.



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EXECUTIVE SUMMARY

# CONTROL OF ZEBRA MUSSELS BY ELECTROSHOCKING

S. McKay
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Electrical Research Department

It is widely believed that zebra mussels were introduced to the Great Lakes water system when a foreign ship discharged its ballast water in Lake St. Clair three to four years ago. Since then, the zebra mussel population has grown significantly and has infested the Detroit River, much of Lake Erie and has spread to the other Great Lakes. This affects power utilities and other water users on the Great Lakes as the mussels can block water intakes and cooling systems. This concern has led to investigations by Ontario Hydro into physical, chemical and electrical methods for controlling zebra mussels in the water systems of power plants.

A literature search was performed to investigate the use of electro-magnetic fields and electric currents for antifouling purposes. Utilization of electric fields has dominated the research and development of apparatus for zebra mussel control, although some work has been performed with magnetic fields. The literature indicates that electric field devices are effective in killing post-veliger and juvenile mussels. Although electric fields have been seen to kill adult mussels, their protective shells increase the power required for favourable mortality rates to prohibitive levels.

The literature indicates that electric currents can effectively defoul adult mussels from conductive surfaces. Trash racks, for example, could be completely cleaned after a day of continuous application. This method can also be used intermittently to minimize power consumption.

A testing program developed with the Chemical Research Department to investigate the effectiveness of electric field devices on juvenile zebra mussels indicates that mussel behaviour can be affected by electric fields. The tests were performed on mussels in a static water environment with a continuous AC power supply. Mussels exposed to electricity for 5 to 90 s generally required more time to recover than the control mussels. Exposure length had no noticeable affect on mussel recovery. The slow recovery of the control indicates that mussel handling prevented an accurate assessment of the short-term effects of electric fields on mussel activity.



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Tests should continue on static water systems to provide additional data for determining the length of electrodes needed for continuous applications. The ultimate goal would be to develop a working model to incorporate the flow conditions in power plant water systems.

Similar tests should be performed with an impulse power supply to investigate the effectiveness of steep front current impulses on the mussels. Literature has been obtained which indicates that an impulse power system is more effective and less energy consuming than a continuous power system.

Tests should be considered for electrified surfaces as this method appears to be an effective means to clear trash racks and other critical surfaces of adult mussels. The goal would be to develop a current-versus-duration relationship for cleaning a fouled surface and to determine the electrical power required to remove mussels from these surfaces.

## TABLE OF CONTENTS


| | | Page |
|---|---|---|
| 1 | INTRODUCTION | 1 |
| 2 | ELECTROSHOCK DEVICES | 2 |
| | 2.1 Electric Fields | 2 |
| | 2.2 Electrified Surfaces | 4 |
| 3 | TEST PROTOCOL | 5 |
| 4 | DEVELOPMENT OF TEST CELL | 5 |
| 5 | RESULTS | 6 |
| 6 | DISCUSSION | 11 |
| 7 | CONCLUSIONS | 12 |
| 8 | RECOMMENDATIONS | 12 |
| ACKNOWLEDGEMENTS | | 13 |
| REFERENCES | | 14 |

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TO: Mr. M.J. Northfield
Manager
Environmental Protection Department
Central Production Services, A7A2

# ELECTROSHOCKING OF ZEBRA MUSSELS

## 1 INTRODUCTION

It is widely believed that zebra mussels were introduced to the Great Lakes water system when a foreign ship discharged its ballast water in Lake St. Clair three to four years ago. Since then, the zebra mussel population has grown significantly and has infested the Detroit River, much of Lake Erie and has spread to the other Great Lakes. This affects power utilities and other water users on the Great Lakes as the mussels can block water intakes and cooling systems. This concern has led to investigations by Ontario Hydro into methods for controlling zebra mussels in the water systems of power plants. An ongoing research program, managed by the Chemical Research Department, is studying the affects of physical, chemical, and electrical mitigation schemes on zebra mussels/1/. Electrical mitigation schemes include cathodic protection and direct electrical devices. This report details the development and testing of an electric field device.

A literature search was performed to investigate the use of electro-magnetic fields and electric currents for antifouling purposes. Utilization of electric fields has dominated the research and development of apparatus for zebra mussel control, although some work has been performed with magnetic fields. These devices have limitations which determine their application. For example, electrostatic filtering is impractical at higher pipe diameters as the power required to operate the filter would be prohibitive.

From this review, a test program was developed with the Chemical Research Department to determine the effectiveness of electric field devices. Tests were performed on zebra mussels in a static water environment with a continuous AC power supply. The mussels were exposed to electric fields for specific durations. This report outlines the direct electrical concepts described in the literature, identifies potential devices for controlling zebra mussels and documents the development and execution of a test program using an electric-field device.

## 2 ELECTROSHOCK DEVICES

A literature search was performed to identify developments in direct electrical antifouling devices for Dreissena polymorpha (zebra mussel) control. The emphasis of the search was placed on both the development of electrical devices and the effects of electricity on post-veliger and juvenile[1] Dreissena and similar species. Relevant publications were obtained primarily from Soviet journals with the balance coming from western European power utilities. Based on this literature search, North American experiences have been limited.

Electrical devices can be driven with continuous, pulsed or impulse power supplies and either with alternating or direct current. Pulsed power supplies provide pulses of continuous power at regular intervals while impulse supplies provide power through the discharge of a capacitor or similar device.

### 2.1 Electric Fields

Electrostatic field systems expose the mussels to an electric field orthogonal to the flow of water as shown in Figure 1. The duration of exposure is determined by the length of the electrodes and the water flow rate. Post-veliger and juvenile mussels would be killed while passing through the electric field/2/. Adult mussels would also perish, albeit, at much higher field strengths.

Typical electrostatic field devices resemble a coaxial configuration where one electrode is placed in the center of the pipe while the interior surface becomes the other electrode. A schematic diagram is provided in Figure 2. Pulsed and impulse driven systems would assume similar configurations. Additional killing potential may arise from the shock waves produced by the intermittent application of power/3/.

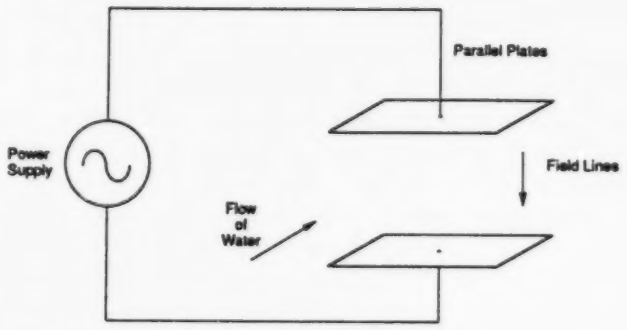


**Figure 1**: Electric Field Configuration

Kirpichenko et. al./2/ performed scoping tests on specimens placed between parallel plates in plexiglass containers. Subsequent tests were then performed on a section of intake piping converted into such a device. Post-veliger mortality was observed at various field intensities. Lower intensities require longer exposure times which depend on the length of the device and the water flow rate. The device was less effective on adults as intensities exceeding 400 V/cm

[1] Mussel growth can be categorized into five stages; namely, egg, veliger, post-veliger, juvenile, and adult. Veliger mussels range from 70 to 300 µm in length. Post-veliger mussel sizes range from 0.3 to 1 mm. Juvenile mussels reach 1 cm in length and have aged 1 year when they become adults. Adult mussels can grow to 4 cm and live 3-5 years.

were needed to compensate for the intrinsic protection offered by the mussel shell. This limited the use of the device due to excessive power consumption.

Burba et.al./4,5/ performed tests on various aquatic life under static conditions to determine the thresholds for stunning and killing the specimens. Impulse and continuous AC as well as DC tests were performed. The data reveals a direct relationship with supply frequency and field intensity. The most favourable results were obtained with DC and low frequency AC (less than 10 Hz) power sources. Impulse and pulsed supplies were as effective as continuous supplies. Pulses of low frequency current were more effective than pulses of higher frequency currents. Finally, the electric field strength required to kill mussels ranged from two to three times that required to stun mussels.

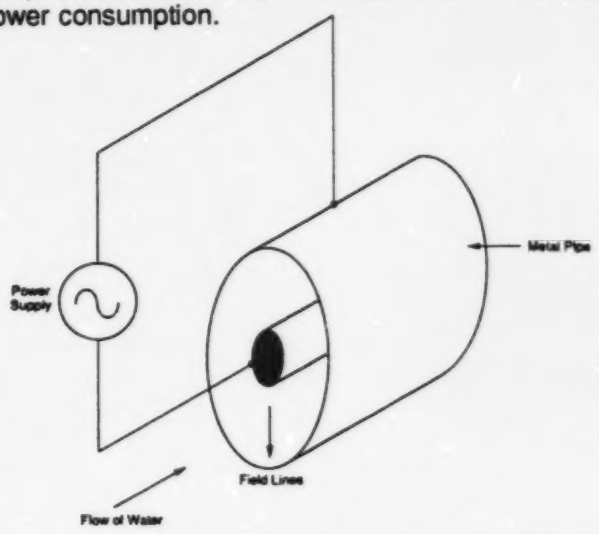


**Figure 2**: Coaxial Pipe Configuration

Vosyliene et.al./3/ investigated the effects of varying frequency, duty cycle[2], exposure duration and field strength of AC electric fields on several aquatic species. Tests showed that increased mortality rates can be realized with decreased supply frequency, increased exposure times or increased field strengths. The effect of the duty cycle on the mortality rate was inconclusive.

Extensive impulse tests were performed on mullusc larvae by Spodobina/6/ with capacitor discharges of various durations. The tests were performed first by varying the test voltage and then the capacitor discharge time. Discharge times vary proportionally with the test circuit capacitance. These tests indicate that high field impulses for long durations would be effective in killing veligers. In one particular test, a mortality rate of 100 percent was achieved at 3.3 kV/cm with a discharge duration of 125 µs.

Static tests using different power supplies were performed by Charlon/7/. Although an ambitious testing protocol was pursued, the results proved inconclusive as the power supplies were not of sufficient strength. However, the study does suggest a minimum intensity level whereby permanent physiological damage can be done to the mussel. From their studies, an application of a 100 V/cm continuous AC field for 0.25 s disabled fifty percent of the specimens.

The literature indicates that electric fields will work effectively as an antifouling device on post-veliger and juvenile mussels but not on adult mussels due to the high voltage required to compensate for the protective nature of the shell. The literature data reflects an exponential relationship between the level of applied electrical intensity and the duration of exposure. This

[2]Duty cycle is the ratio of signal "on" time to signal period. For example, a duty cycle of 1 would represent continuous DC current.

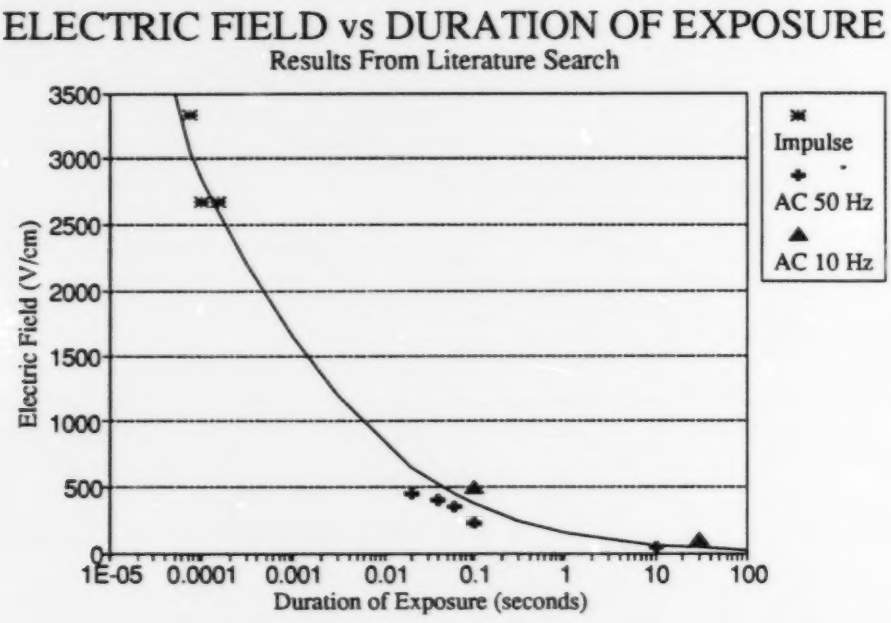


**Figure 3**: Summary of Literature Data: Electric Field vs Duration of Exposure

can be seen in Figure 3 where all of the pertinent data is compared. Data from parallel plate and coaxial pipe configurations are typically expressed as electric fields instead of current density. Current density is difficult to maintain as the water conductivity changes during the test. A general consensus over which power supply is the most effective is not available. While some favoured DC, others reported no particular advantage at frequencies less than 100 Hz. Conversely, results from Burba's experiments comparing low frequency AC with DC show DC to be only half as effective as AC for the same test parameters.

### 2.2 Electrified Surfaces

Electric currents can be used to detach adults which have attached themselves to trash racks and other conductive surfaces. The adults are unable to withstand the current flow and ultimately detach themselves from the surface. Such devices, operating at low current, generally require a day to kill or immobilize attached mussels. This duration can be reduced with higher currents. A typical configuration is provided in Figure 4.

V.A. Shentyakov/8/ studied trash rack electrification and determined a relationship between current density and defouling time. Tests were repeated at various current densities to determine the asymptotic limits of current magnitudes in winter and summer water conditions. Similar results were obtained with continuous and pulsed currents.

An electrified grill was designed by LaMarque/9/ to stress veligers with a field of 100 V/cm at 100 Hz for 250 ms. The grill consisted of vertical conducting plates spaced 8 cm apart with

voltage being applied to each pair of plates. Plate width was 7.5 cm to ensure a 250 ms exposure based on a water intake flow rate of 0.3 m/s. The overall size of the grill was 8.4 m deep by 2.2 m wide and was capable of treating 5.5 $m^3$ of water per second. The test compared a pulsed power supply with a capacitor discharge set. The pulsed supply required 40 MW to perform effectively. The capacitor discharge set yielded the same performance while only consuming 3.2 kW. Empirical observations indicate that the grill plates were quickly defouled of mussels when the tests were performed. However, chlorine was produced by electrolysis of the treatment water.

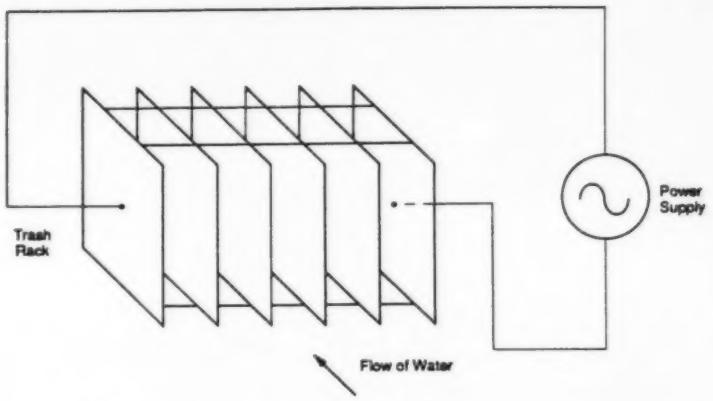


**Figure 4**: Trash Rack Model

## 3 TEST PROTOCOL

The overall goal of the test program was to establish the design parameters necessary for the development of electric field devices (EFD) and their effectiveness in preventing settlement of zebra mussels in water systems. Experiments on electrified surfaces were not performed in this program. The EFD parameters were determined through experimentation based on data obtained from the literature search described in this report and summarized in Figure 3. An electric field device was built for this purpose and a testing protocol was developed for conducting the experiments.

Tests were designed to determine the relationship between electric field strength and duration of exposure with an emphasis on the time required for mussels to recover from treatment. Electric fields of up to 500 V/cm for durations ranging from 0.1 to 90 s were used to find the optimum exposure level. Test durations greater than 90 s were impractical since long duration exposure rates would be difficult to implement in continuous flow systems.

Static testing was performed with a continuous AC power supply on juvenile mussels in the 3-6 mm size range. Each test group was limited to 25 specimens which provided a good statistical sample and minimized handling time. The specimens were collected in de-chlorinated water, transferred to de-ionized water for the test and then returned to de-chlorinated water for subsequent analysis. The specimens were then inspected at regular intervals with a microscope using a magnification factor of six to determine the recovery time of the mussels. Finally, the specimens were killed with sodium hypochlorite (NaOCl) solution to facilitate safe disposal.

## 4 DEVELOPMENT OF TEST CELL

A plastic and stainless steel test cell was developed for the static testing program. The cell consists of 10 cm diameter acrylic pipe placed between two electrodes representing the anode

and cathode at each end of the pipe section. The cathode is situated between the plastic cell wall and bottom plate. The anode is suspended from a cross bar and can be lowered to a particular height by adjusting a set screw. A fine screen mesh lies between the two stainless steel electrodes. This mesh is friction-fitted to the cell and is used as a support surface for the mussels. A photograph of the test cell is shown in Figure 5.

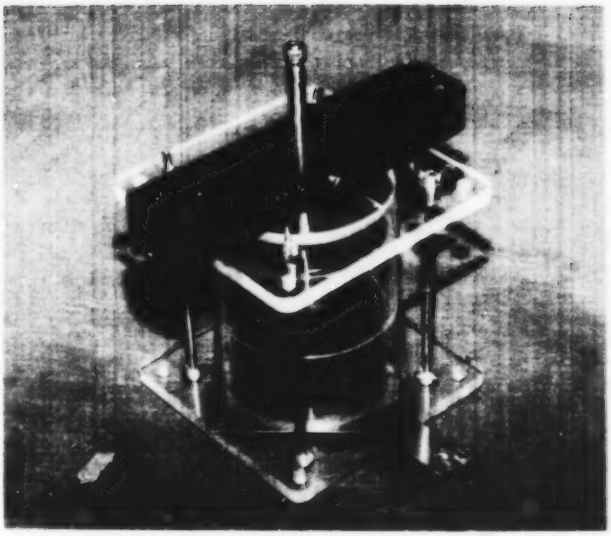

**Figure 5** : Photograph of Zebra Mussel Test Cell

The top plate is secured to the bottom plate with four bolts which ensures a tight seal between the wall piece and bottom plate. This pressure fit method was used instead of sealants to prevent impurities from leaching into the cell and contaminating the water. This could have adverse affects on the testing performance as these impurities may kill the mussels.

The electrical resistance of this device is proportional to the distance between the two electrodes and inversely proportional to the surface area of each electrode and the conductivity of the medium. Constant resistance was unavailable because the water temperature increased as current flowed through the test cell. This temperature rise increased the conductivity of the water which increased the current flow until the current limit on the transformer was reached. This was observed on an oscilloscope which monitored both current and voltage waveforms.

De-ionized water was ultimately used in the test program to compensate for limitations with the available power supply. The performance of such a device at a generating station would depend on the lake water conductivity which can range from 100 to 200 times that of de-ionized water/10,11,12/.

## 5 RESULTS

Tests were first performed to verify experiments described in the literature. The documented experiments included tests performed for durations of 0.1 and 10 s. Additional points were selected between 0.1 and 90 s to gain further information on the response of mussels to electricity. A graph of the test parameters for each group is provided in Figure 6.

In the first series of tests, mussels were subjected to high electric fields for short durations. Four groups were subjected to 500 V/cm (650 $\mu A/cm^2$) for 0.1 s while two other groups received 365 V/cm (525 $\mu A/cm^2$) for 0.65 s. The first group experienced a lower voltage and higher current density than the others because of high water conductivity resulting from de-chlorinated water being introduced into the de-ionized water of the test cell. The mussels that were tested remained stunned for 2 to 3 h and had recovered by the end of the day. The control mussels

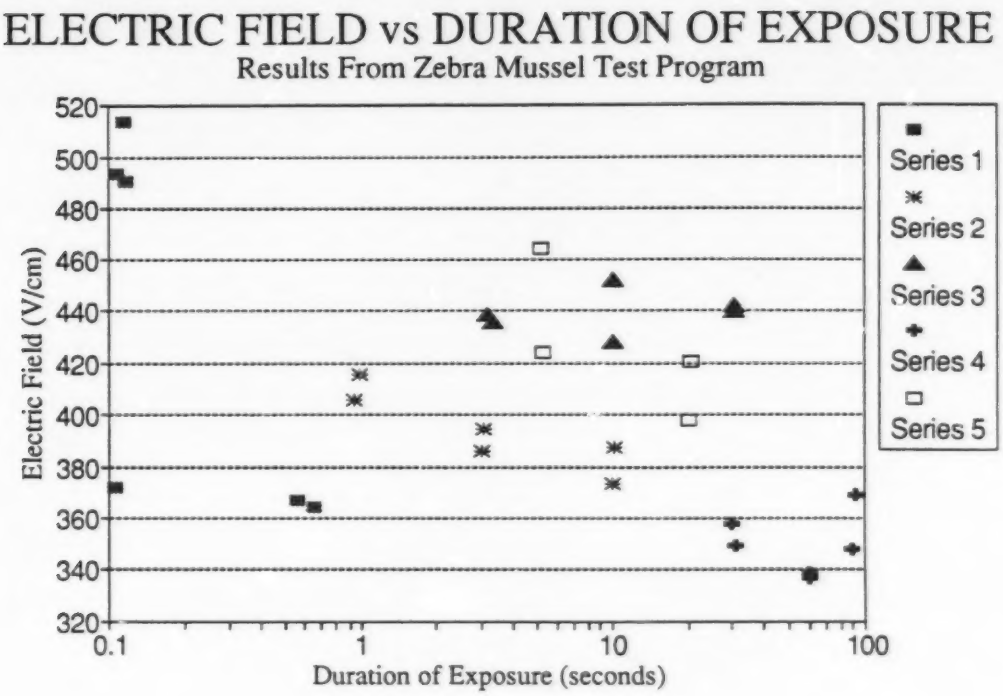


**Figure 6** : Electric Field vs. Duration - Experimental Data

completely recovered within 3 h after the test. Table 1 lists the data from the first three series of tests.

The second series of tests had six groups of mussels being subjected to electric fields ranging from 375 to 415 V/cm with the current density ranging from 545 to 585 $\mu A/cm^2$. Of the six groups, two groups each were subjected to 1, 3, and 10 s exposures. The mussels had completely recovered within 4 h after the test. On two of the tests, the mussels were seen to move when the voltage was applied and removed. The mussels had aligned themselves with the electric field such that the field cut through the least amount of mussel shell surface area.

The third series of tests subjected the mussels to electric fields between 425 and 455 V/cm for durations of 3, 10, and 30 s. The current density ranged from 507 to 570 $\mu A/cm^2$. Very little activity was observed within the first hour in all six groups. The majority of the control had recovered within 5 h.

Electric fields ranging from 335 to 370 V/cm for durations of 30, 60 and 90 s were applied to the six groups of mussels in the fourth series of tests. Current density varied from 425 to 470 $\mu A/cm^2$ for these tests. Each group was inspected on an hourly basis for signs of activity. The average mussel recovery time for these tests is plotted with the recovery time for the control group in Figure 7. The test data for these series of tests is given in Table 2. The control had the fastest recovery although full recovery required 22 h. Full recovery of the test

specimens required 24 to 26 h. One mussel, which was climbing toward the air/water interface, fell off the wall when the power was applied. It was part of the fifth group which received 369 V/cm and 425 $\mu A/cm^2$ for 92 s.

Three groups of mussels were tested in the fifth series. The first two groups were exposed to an average of 445 V/cm for 5 s while the third group was exposed to 420 V/cm for 20 s. The current density varied from 515 to 600 $\mu A/cm^2$. Each group was inspected on an hourly basis for signs of activity. The pertinent test data are given in Table 3, while the recovery times for the three groups and the control are plotted in Figure 8. There was no significant difference in recovery between the groups exposed for 5 s and the group exposed for 20 s. The control recovered more slowly in this test series than the previous series. Full recovery was not realized until 78 h after the test. A videotape confirmed previous observations of mussels aligning themselves with the electric field lines.

| TEST SERIES | ELECTRIC FIELD V/cm | DURATION s | PEAK CURRENT mA | CONDUCTIVITY $\mu S/cm$ | CURRENT DENSITY $\mu A/cm^2$ |
|---|---|---|---|---|---|
| #1 | 371.94 | 0.11 | 63.50 | 3.46 | 1286.91 |
| | 513.36 | 0.12 | 55.00 | 1.22 | 626.30 |
| | 493.56 | 0.11 | 56.50 | 1.33 | 656.44 |
| | 490.73 | 0.12 | 57.25 | 1.35 | 662.49 |
| | 364.16 | 0.65 | 45.00 | 1.41 | 513.47 |
| | 366.99 | 0.56 | 47.50 | 1.45 | 532.14 |
| #2 | 405.88 | 0.94 | 53.00 | 1.39 | 544.67 |
| | 415.78 | 0.99 | 52.00 | 1.31 | 564.17 |
| | 386.08 | 3.09 | 53.50 | 1.44 | 555.96 |
| | 394.57 | 3.04 | 53.50 | 1.40 | 552.40 |
| | 373.35 | 10.11 | 56.00 | 1.57 | 586.16 |
| | 387.49 | 10.16 | 58.00 | 1.47 | 569.61 |
| #3 | 436.30 | 3.33 | 50.00 | 1.16 | 507.85 |
| | 438.40 | 3.19 | 49.75 | 1.16 | 509.42 |
| | 428.51 | 10.12 | 54.25 | 1.19 | 534.35 |
| | 452.55 | 10.11 | 50.50 | 1.25 | 537.18 |
| | 442.60 | 30.10 | 53.00 | 1.29 | 570.95 |

Table 1: Test Data From Test Series #1-3

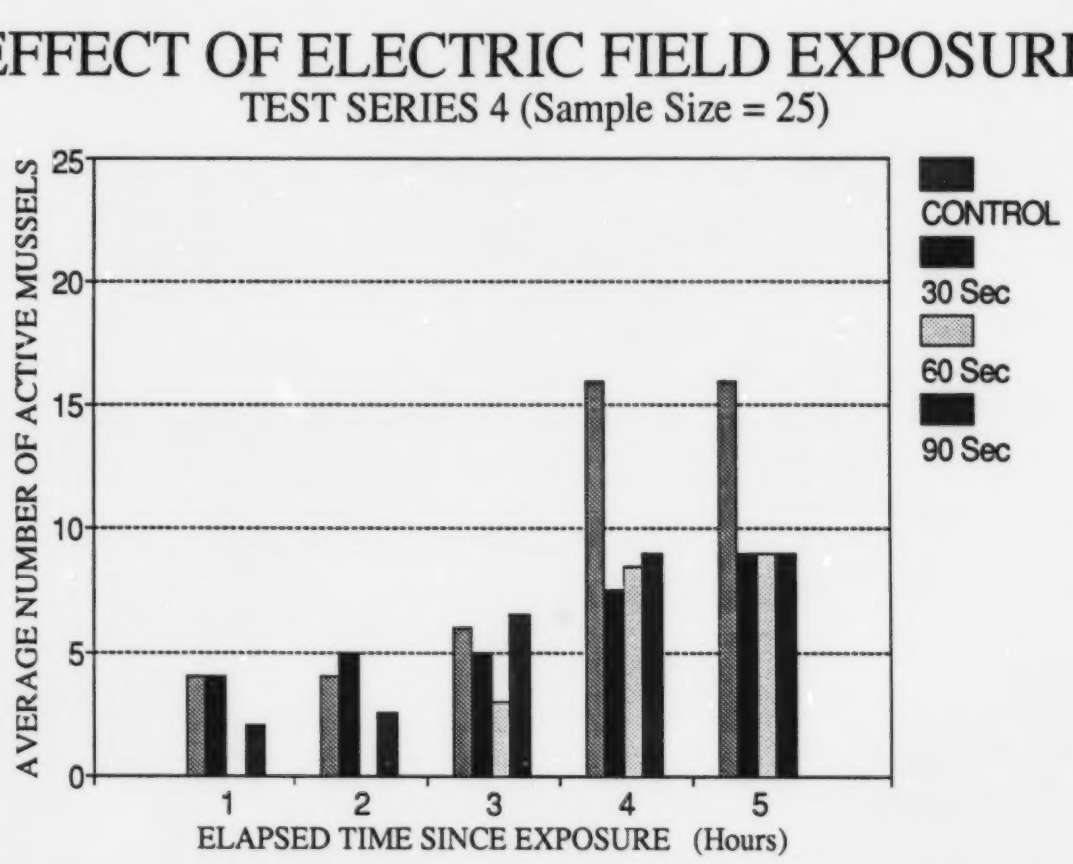


**Figure 7**: Average Recovery Time of Mussels for Test Series #4

| GROUP NUMBER | ELECTRIC FIELD V/cm | DURATION s | PEAK CURRENT mA | CONDUCTIVITY µS/cm | CURRENT DENSITY µA/cm² |
|---|---|---|---|---|---|
| 1 | 349.36 | 30.40 | 43.50 | 1.24 | 433.21 |
| 2 | 357.85 | 29.99 | 43.25 | 1.29 | 461.63 |
| 3 | 336.63 | 60.00 | 42.75 | 1.32 | 444.35 |
| 4 | 338.76 | 60.17 | 45.25 | 1.39 | 470.88 |
| 5 | 369.17 | 92.00 | 42.00 | 1.15 | 424.55 |
| 6 | 347.95 | 90.00 | 43.50 | 1.27 | 441.80 |

Table 2: Test Data for Test Series #4

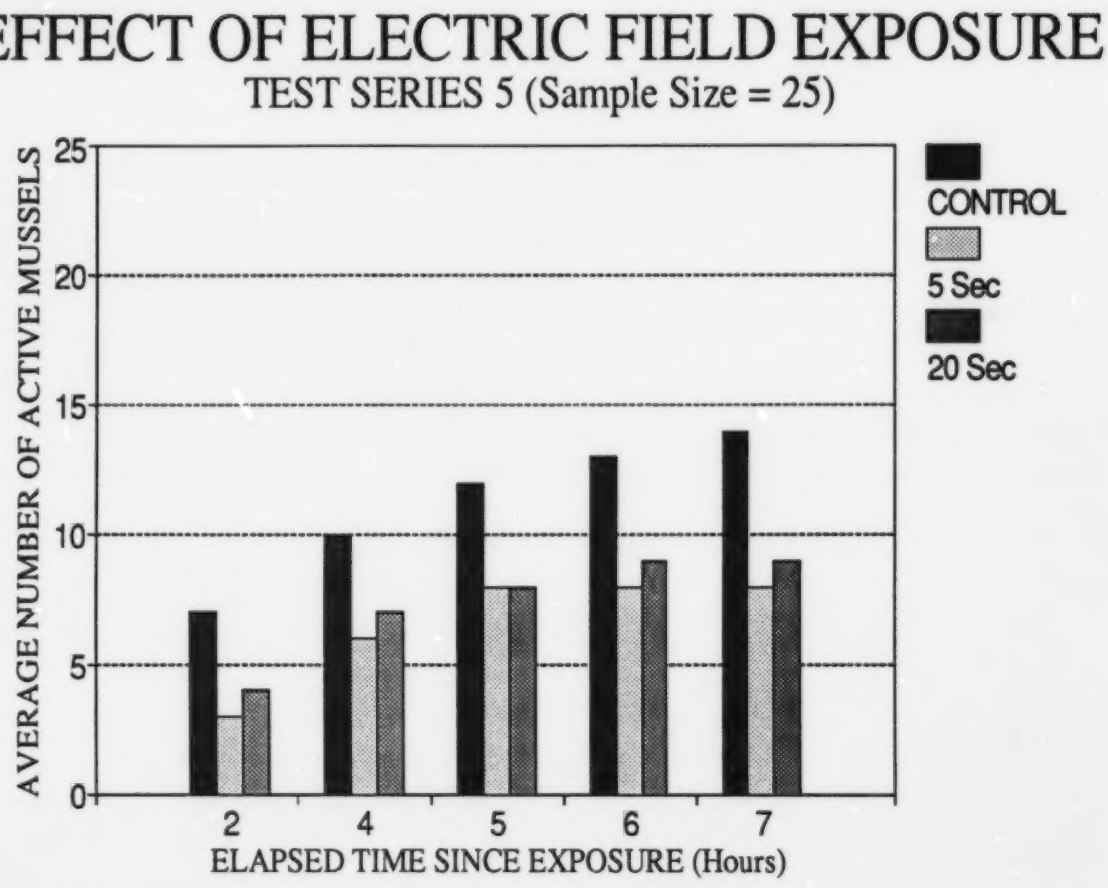


**Figure 8**: Average Recovery Time of Mussels for Test Series #5

| GROUP NUMBER | ELECTRIC FIELD V/cm | DURATION s | PEAK CURRENT mA | CONDUCTIVITY µS/cm | CURRENT DENSITY µA/cm² |
|---|---|---|---|---|---|
| 1 | 464.6 | 5.151 | 48.75 | 1.11 | 515.75 |
| 2 | 423.6 | 5.302 | 55.25 | 1.40 | 593.07 |
| 3 | 420.7 | 20.37 | 53.75 | 1.42 | 597.52 |

Table 3: Test Data for Test Series #5

## 6 DISCUSSION

Power consumption is a concern with electric field devices. The test cell consumed 250 W during the static testing program using de-ionized water (conductivity of about 2.0 µS/cm). Similar tests with lake water would require 6.25 kW to maintain a gradient of 500 V/cm. The current flowing through the cell would be 1.25 A based on a water conductivity of 300.0 µS/cm. Increasing the size of the device will increase its power consumption. An alternative would be to use an impulse power supply. LaMarque/9/ suggests as little as 10% of the continuous power requirements would be needed to realize the same effect.

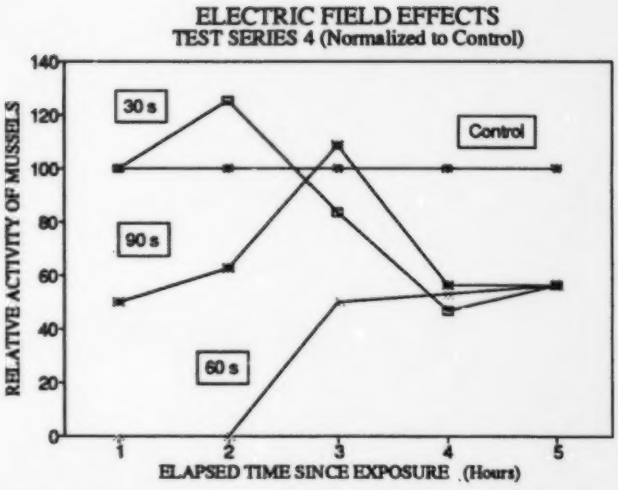


**Figure 9**: Normalized Mussel Activity for Test Series #4

Four to five hours were required for a 50 % recovery of the controls while full recovery required over 22 h. The slow recovery time may be attributed to the handling of the mussels or the use of de-ionized water. The handling procedure introduces the potential of physical damage from manipulation while de-ionized water could cause osmotic shock to the mussel.

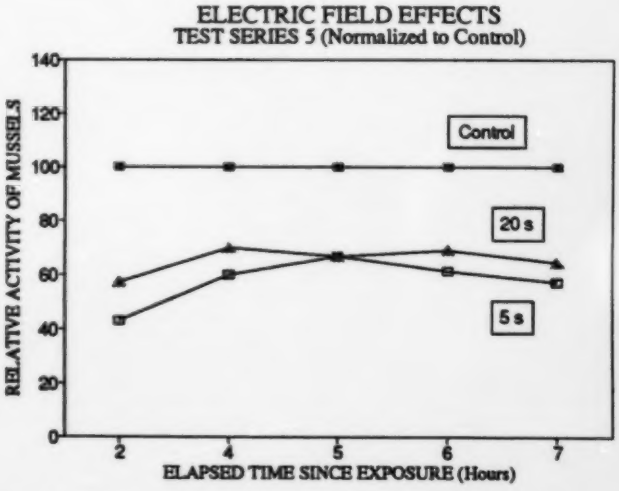


**Figure 10**: Normalized Mussel Activity for Test Series #5

In order to illustrate the relative recovery rates for mussels exposed to electric fields, relative activity values were calculated in comparison to the control samples for test series #4 and #5. This data is given in Figures 9 and 10. Figure 9 shows that the control recovered more slowly than the 30 s and 90 s tests for the first three hours. Figure 10 shows that the tested groups recovered more slowly than the control. The slow recovery of the controls in both test series supports the theory that the handling procedure suppresses mussel activity and inhibits determining the effects of electric fields on zebra mussels for the first few hours after the testing has been completed.

## 7 CONCLUSIONS

Electric fields have been shown in the literature to be effective as an antifoulant, particularly with post-veliger and juvenile mussels. One Soviet paper indicates some success from an experiment where an intake pipe section had been converted into a coaxial capacitor-like device. Although electric fields have been reported to kill adult mussels, their protective shells increase the voltage required for favourable mortality rates to prohibitive levels. However, performance on adult mussels may not be an issue as the desirable zebra mussel control strategy is to prevent settlement of veligers.

From the literature, it is clear that surfaces can be defouled using electric currents. Soviet tests show that surfaces can be cleaned after a day of continuous electrification and that the apparatus can be successfully used intermittently thereby reducing power consumption. French tests have shown that pulsed and impulse currents also effectively defouled the surfaces of their test apparatus although specific data were not available.

A static testing program developed with the Chemical Research Department to investigate the effectiveness of electric field devices on juvenile zebra mussels indicates that mussel behaviour can be affected by electric fields. Tests from 0.1 to 90 s duration were conducted. Treated mussels generally required more time to recover than the control mussels for exposures ranging from 5 to 90 s. The length of exposure had no noticeable affect on mussel recovery. The slow recovery of the control indicates that the handling procedure prevented an accurate assessment of the short-term effects of electric fields on mussel activity.

## 8 RECOMMENDATIONS

Tests should continue on static water systems to provide additional data for determining the length of electrodes needed for continuous applications. The ultimate goal would be to develop a working model to incorporate the flow conditions in power plant water systems. This could then be scaled up for use in the zebra mussel test rig at the Nanticoke Generating Station.

Similar tests should be performed with an impulse power supply using lake water and improved handling procedures. These tests would investigate the effectiveness of steep front current impulses on the mussels. The improved handling procedure and use of lake water would allow the investigation of short term (less than 1 h) effects on mussels. Literature has been obtained which indicates that impulse power is more effective than continuous power and that impulse systems will consume far less power.

Tests also should be considered for electrified surfaces as this method appears to be an effective means to clear adult mussels from trash racks and other critical surfaces. The goal would be to develop a current-versus-duration relationship required to fully clean a fouled surface. A preliminary study would involve developing a scale model of the trash rack system which would provide data necessary for determining the requirements for a full scale application.

**ACKNOWLEDGEMENTS**

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Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

S.R. McKay
Engineer
Utilization Section

Reviewed by:

J.T Strack
Unit Head-Process Applications
Utilization Section

SM:djb

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